DRAFT

U.S. ATLAS HL-LHC Upgrade Technical Overview

Hal Evans
U.S. ATLAS HL-LHC Technical Coordinator
Indiana University

U.S. ATLAS HL-LHC Upgrade Director's Review
Brookhaven National Laboratory
Upton, New York
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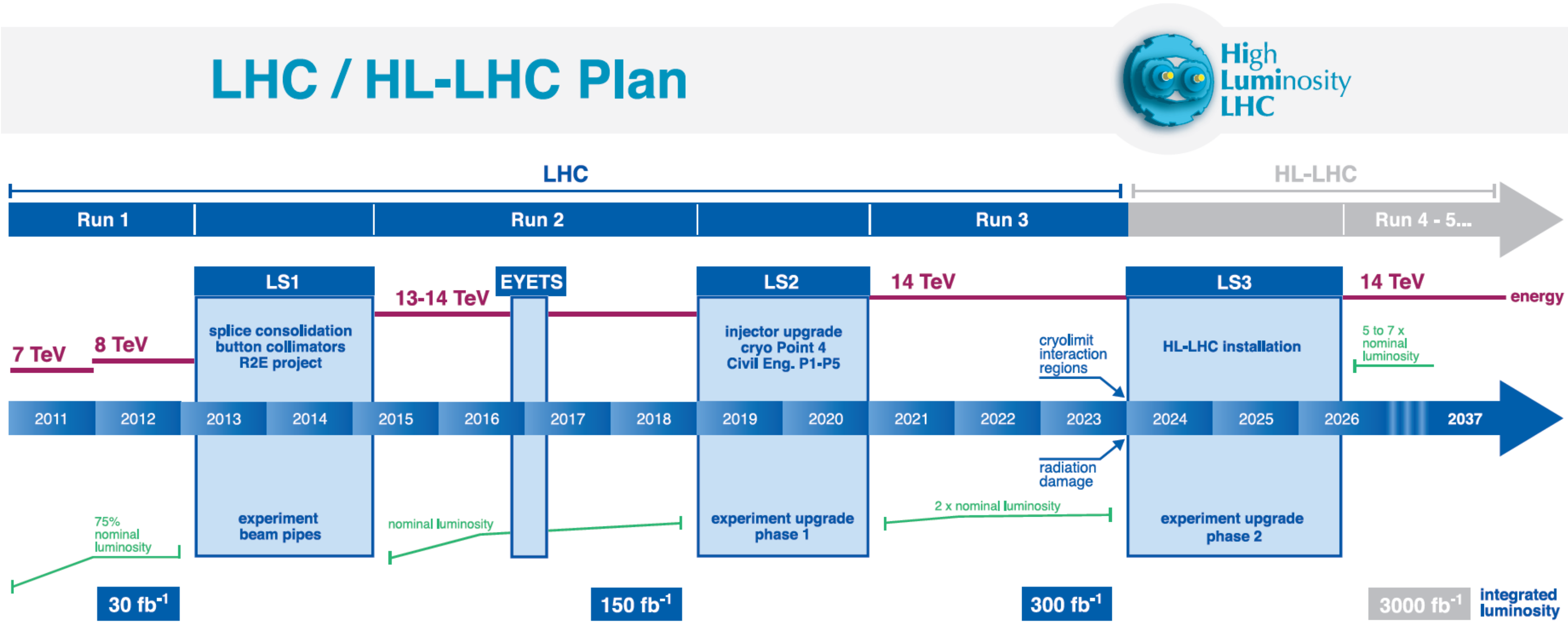
Outline

- Motivation for the HL-LHC Upgrades
- Overview of the ATLAS HL-LHC Upgrade
- Proposed U.S. Role
- Ongoing R&D Effort in the U.S.
- Not Covered Here
  - Management, Budgets, etc.: see talks by Srini and Mike
  - Sub-System Details: see talks by L2 Managers

LHC Evolution

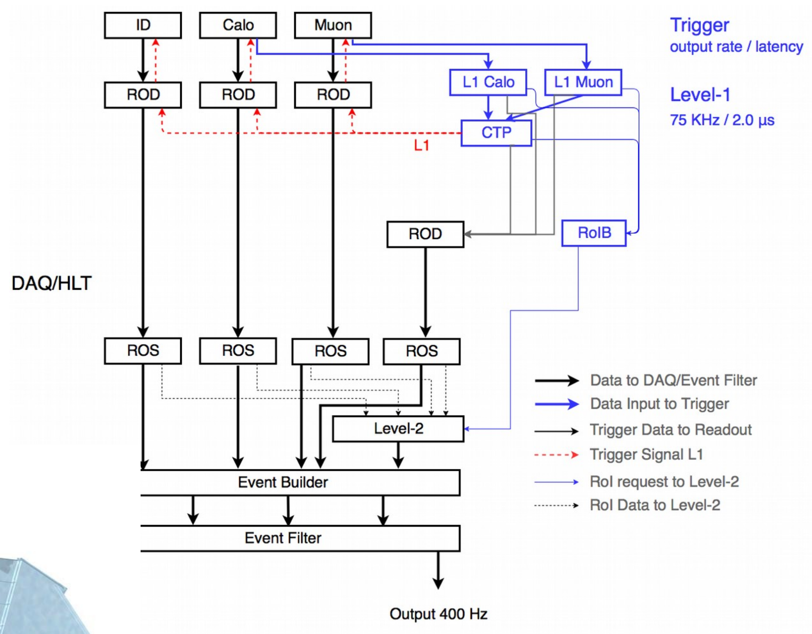


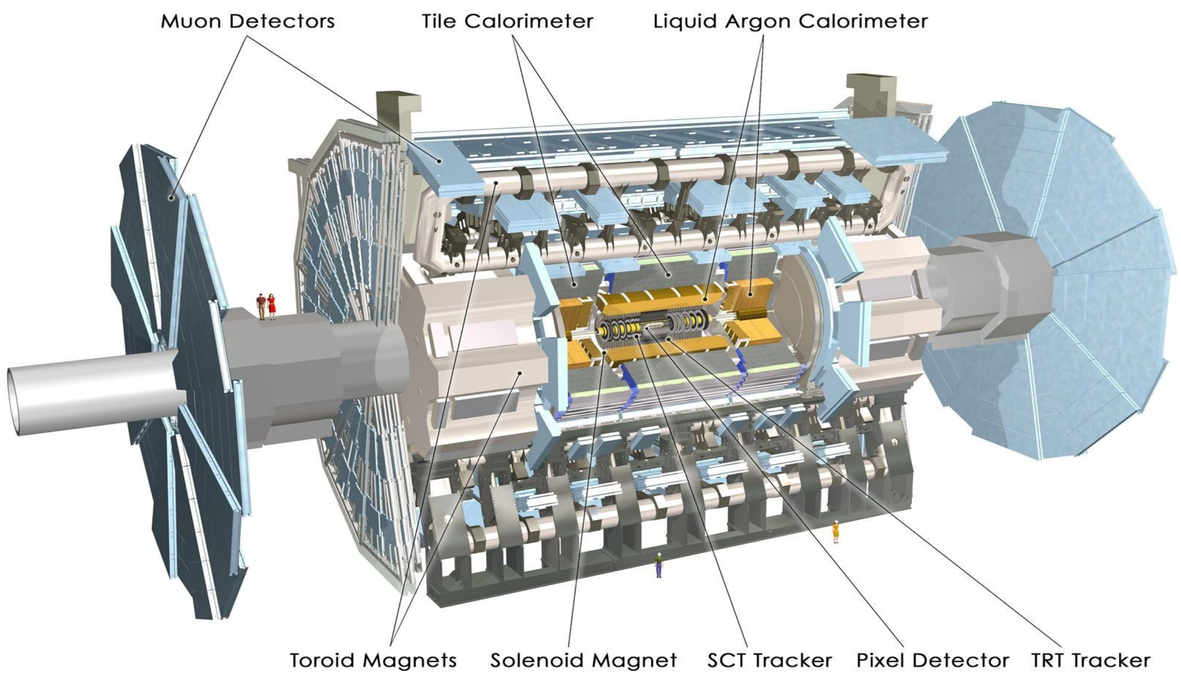
Run	Years	Energy (TeV)	Bunch Spacing (ns)	Peak Lumi (x 10^{34} cm^{-2} s^{-1})	Pileup	Total Int. Lumi (fb^{-1})
1	2010-12	7,8	50	0.75	20	30
2	2015-18	13,14	25	1.6	43	150
3	2021-23	14	25	2-3	50-80	300
4...	2026...	14	25	5-7.5	140-200	3,000

ATLAS Evolution: Run 1

2012 ATLAS Detector

- Inner Detector: Silicon pixels & strips, TRT
- Calorimeters: Liquid Argon, Scint. Tile, FCAL
- Muon: RPC, TGC (trig), MDT, CSC (precision)
- Forward: LUCID, ZDC, ALFA
- Magnets: 2T solenoid (track), toroid (muon)





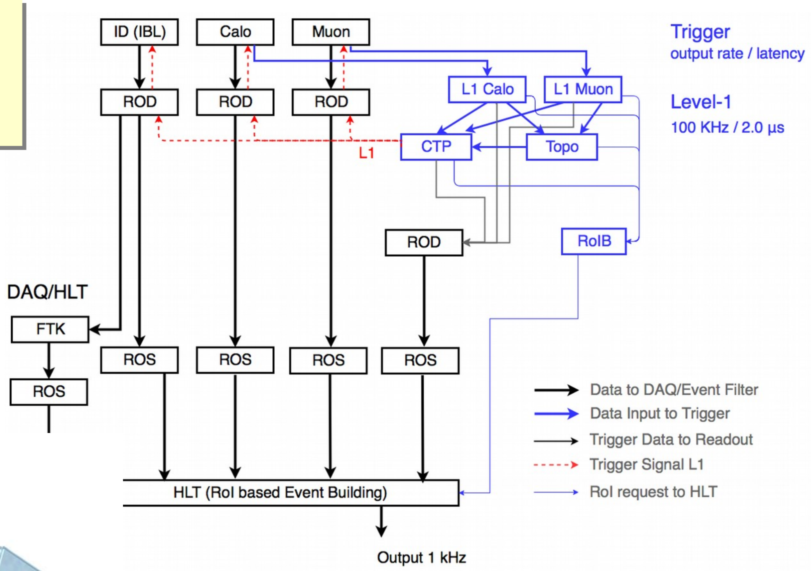
2012 Trigger/DAQ

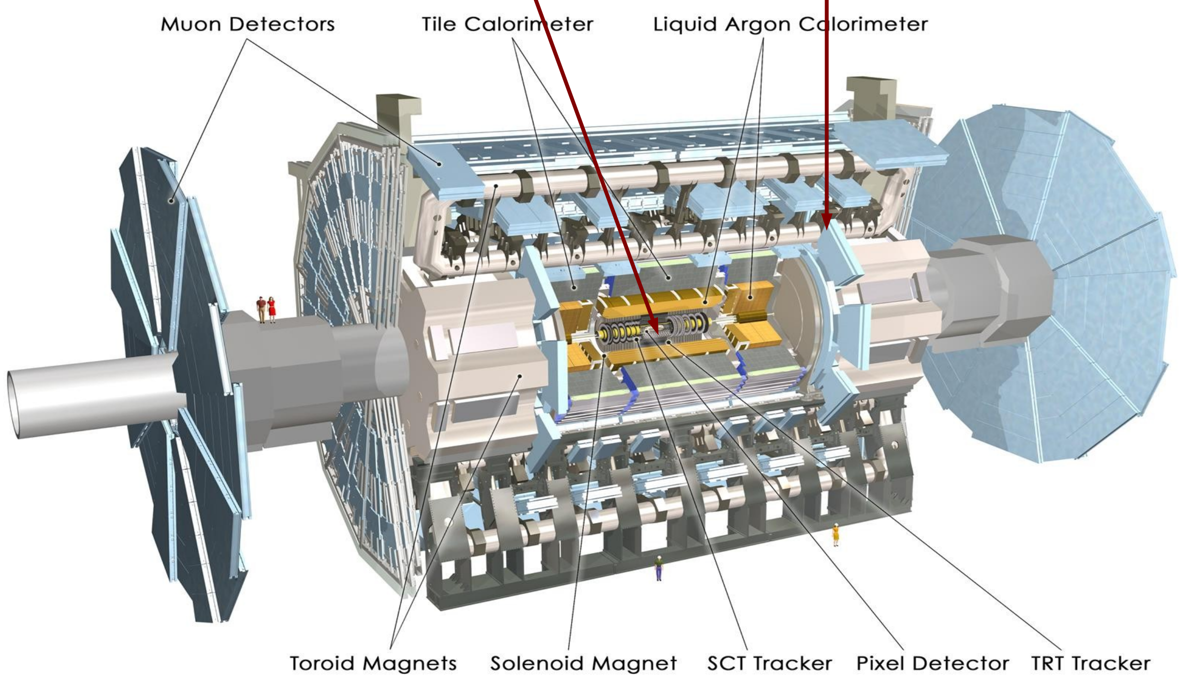
- 3-Level System
  - L1: Calo + Muon
  - L2: RoI-based
  - EF: similar to offline
- Data Acquisition
  - 400 Hz to tape

ATLAS Evolution: Run 2

Phase-0 Upgrades
- effective operations at 1.6 x design lumi

Main Detector Changes
- Inner Detector: inner silicon layer (IBL)
- Muons: CSC readout, endcap completed
- Forward: all upgraded (+ AFP)

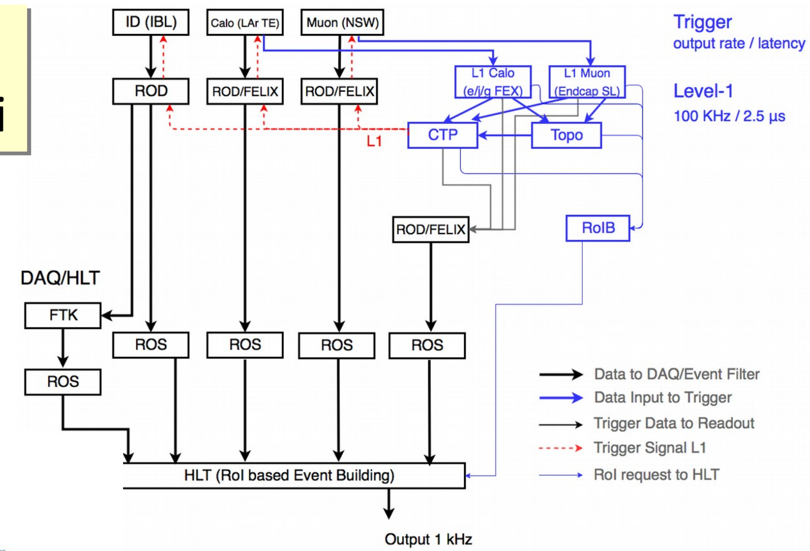




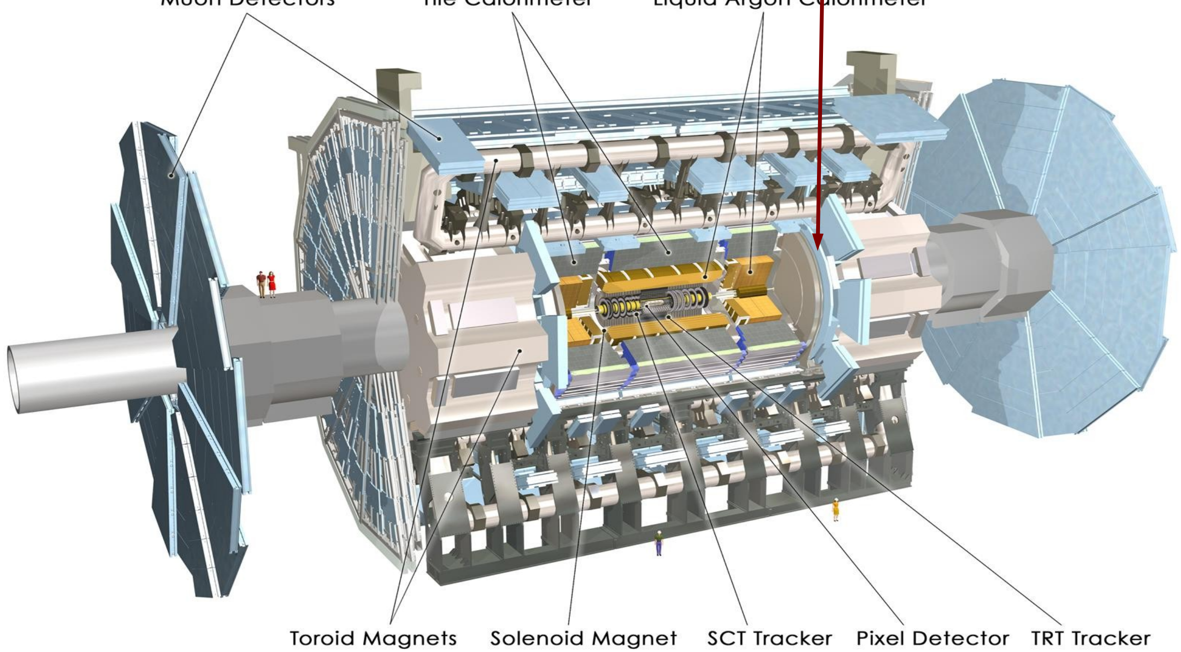
Trigger/DAQ Changes
- L1 Topological Trigger
- Fast Tracker (FTK) → L2
- Merge L2 and EF
- Simplify Dataflow

ATLAS Evolution: Run 3

Phase-I Upgrades
- effective operations at 2-3 x design lumi



Main Detector Changes
- Muon: New Small Wheel (NSW)
- Calorimeter: LAr trigger electronics



Trigger/DAQ Changes
- L1Calo Feature Extractors (e/j/gFEX)
- NSW to Muon Trigger
- Topology & Central Trigger
- Complete FTK
- FELIX data distribution

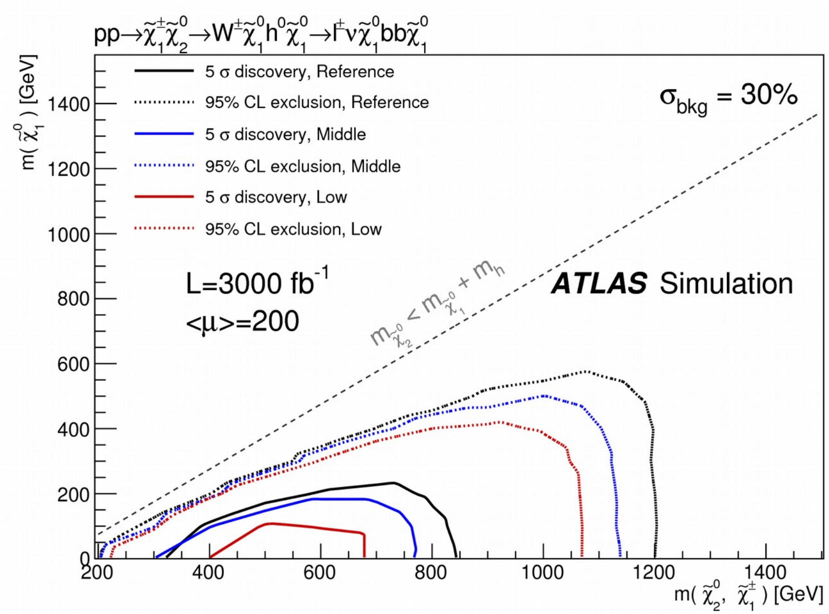
HL-LHC Opportunities

- HL-LHC Focuses on 3 of P5 Science Drivers
  - Use the Higgs boson as a new tool for discovery
  - Pursue the physics associated with neutrino mass
  - Identify the new physics of dark matter
  - Understand cosmic acceleration: dark energy and inflation
  - Explore the unknown: new particles, interactions, and physical principles
- Physics Opportunities with 3,000 fb^{-1} across all ATLAS physics areas
  - x100 more than current dataset, x10 more than anticipated Run-3 data
- ATLAS has chosen a few specific channels to optimize HL-LHC detector design
  - sensitive to performance of different physics questions and detector element performance
  - Higgs Properties (mass, couplings)
    - $H \to 4\mu$, VBF $H \to ZZ^{(*)} \to 4\ell$ and $H \to WW^{(*)} \to \ell\nu\ell\nu$
  - Electroweak Symmetry Breaking (Higgs)
    - same-sign WW production via Vector Boson Scattering (VBS ssWW)
  - Supersymmetry (specific new physics model with potential Dark Matter candidate)
    - $\chi_1^{\pm} \chi_2^0 \to \ell bb+X$
  - Other New Physics
    - KK Graviton decays to Higgs pairs that decay to b-quarks ($HH \to 4b$)

ATLAS HL-LHC Physics Reach

- Sensitivity Improvements in Example Channels ==> Physics Goals
  - studied using parameterized sim. of HL-LHC detector options under HL-LHC conditions
    - 3 detector configurations considered to probe sensitivity to design assumptions
      - Reference, Middle, Low
  - Reference: maintains/improves current level of performance
    - significant degradations in Middle and Low scenarios (see Scoping Doc for details)

Channel	Quantity	Run-1 Result	Target HL-LHC Sensitivity
$H \to 4\mu$	relative uncertainty on production	22%	2.2%
VBF $H \to ZZ^{(*)} \to 4\ell$	relative uncertainty on production	360%	17% (7.6σ)
VBF $H \to WW^{(*)} \to \ell\nu\ell\nu$	relative uncertainty on production	36% (3σ)	20% (5.7σ)
VBS ssWW	relative uncertainty on production	34% (3.6σ)	5.9% (11σ)
SUSY $\chi_1^{\pm}\chi_2^0 \to \ell bb + X$	chargino/neutralino mass	>250 GeV (95% CL)	850 GeV (5σ observation)
BSM $HH \to 4b$	K-K graviton production	---	4.4σ (at M = 2 TeV)

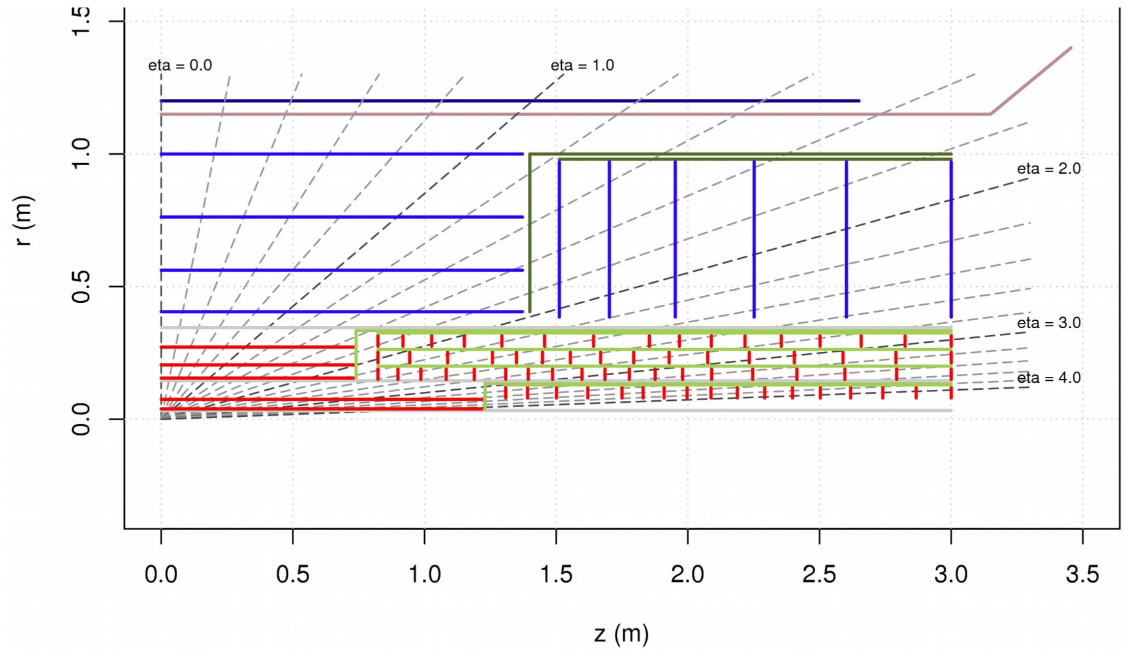


HL-LHC Constraints on ATLAS

- Run-3 ATLAS Detector cannot meet HL-LHC Physics Goals
  - Accumulated Radiation Dose ==> current Inner Detector inoperable
    - integrated charge also causes problems for some Muon detectors
  - High Instantaneous Luminosity ==> complex events
    - 200 pileup collisions per bunch crossing: x7.5 larger than design
    - particularly an issue for the lowest level triggers
  - Rate + Complexity ==> x10 data volume increase
    - data acquisition & computing infrastructure must deal with this
- Science Requirements for HL-LHC Detector & Trigger
  - charged particle tracking that maintains Run-1 levels of performance in the high pileup environment of the HL-LHC;
  - trigger selection of events for permanent storage at an average rate of ~10 kHz (out of the 40 MHz bunch crossing rate) with thresholds that maintain at least Run-1 levels of efficiency for interesting physics processes;
  - data acquisition (DAQ) and data handling that must deal with data volumes more than an order of magnitude larger than those encountered in Run-1.

Overview of ATLAS HL-LHC Upgrades

- Tracker
  - complete replacement of current Inner Detector with a new all-silicon Inner Tracker (ITK)
    - pixels and strips
    - coverage to $|\eta|=4.0$
  - all-new electronics
    - allows operation with new trigger architecture
    - input to Level-1 Tracking Trigger

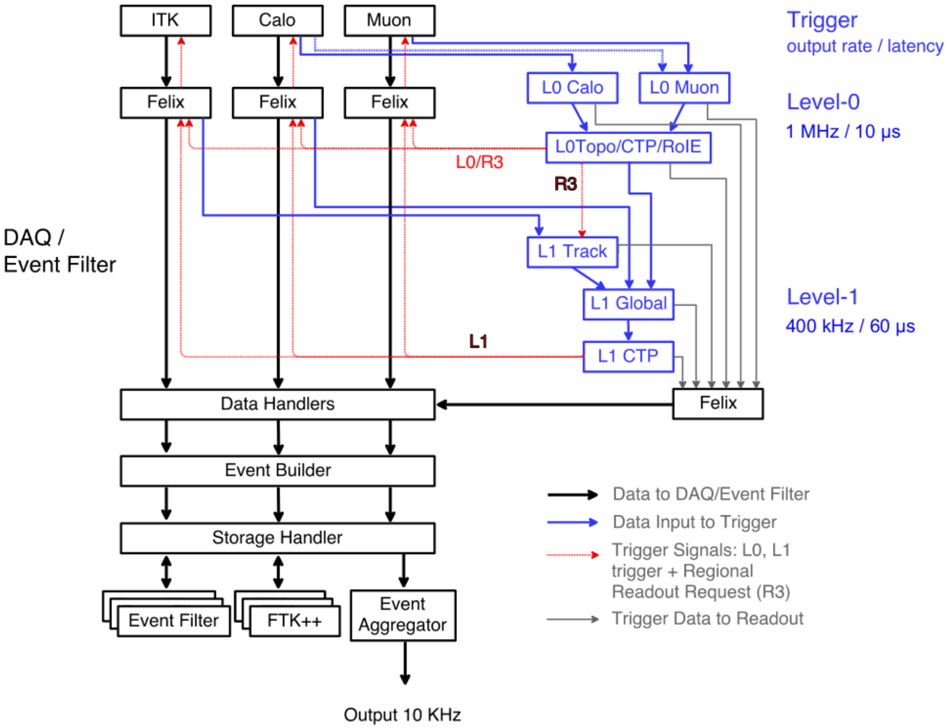


Layout changed from Scoping Doc
- 4(pixel) + 5(strip) ==> 5(pixel) + 6(strip) layers

U.S. DOE

ATLAS HL-LHC Upgrades (2)

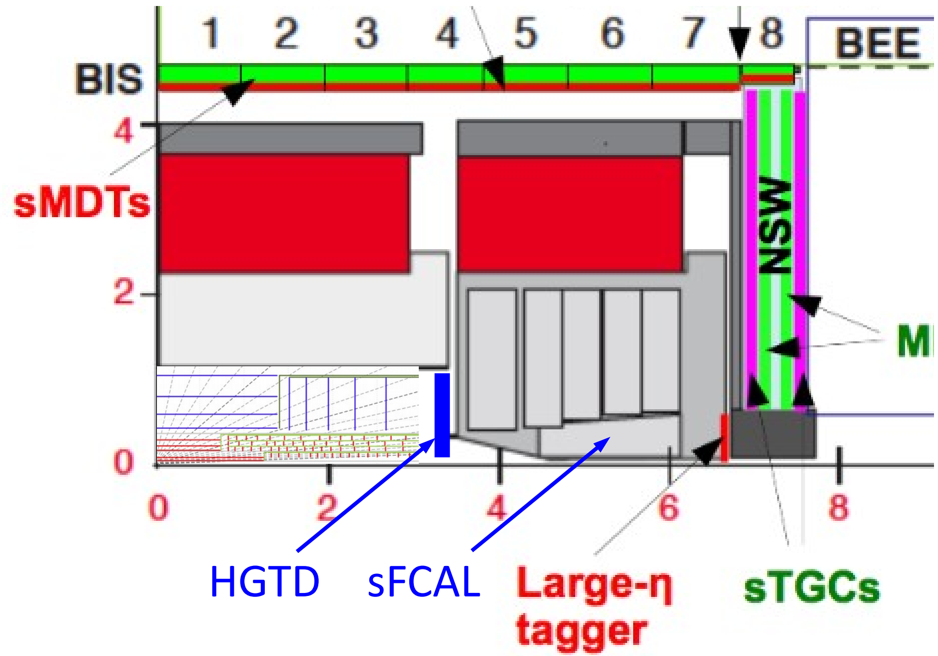
- DAQ & Data Handling
  - upgrades to handle larger data volume/rate
    - Data Acquisition (DAQ) & Event Filter (EF)
    - Increases:
      - L1 rate: x4
      - Raw event size: x2.5
  - data distribution electronics for trigger system



U.S. DOE

ATLAS HL-LHC Upgrades (3)

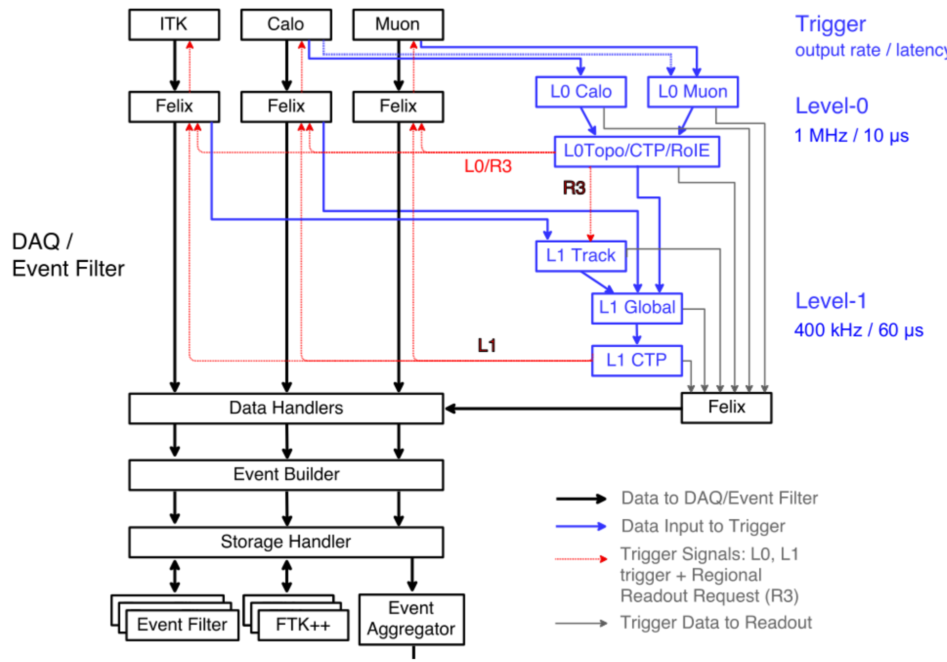
- Trigger-related Hardware
  - replace FCAL with high-granularity sFCAL
    - improved jet/E_T^{miss} and electron performance
  - add High Granularity Timing Detector (HGTD)
    - $2.3 < |\eta| < 4.3$
    - pileup rejection in poorly covered region
  - add Very Forward Muon Tagger (Large-η Tagger)
    - extend muon coverage to $|\eta| = 4.0$

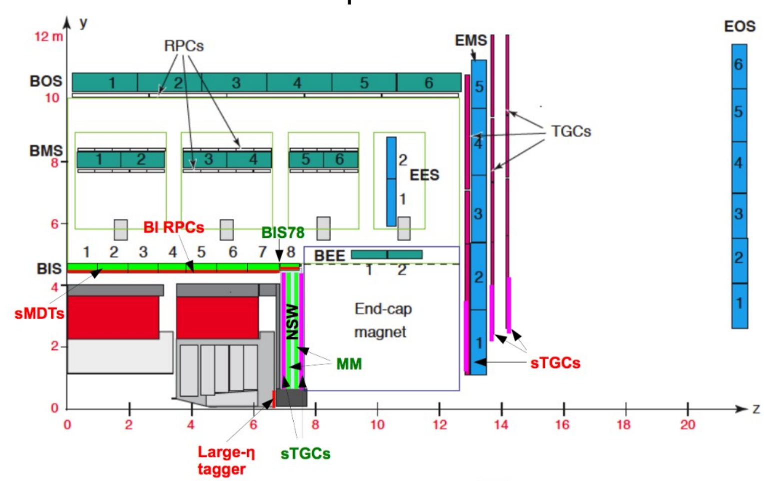


U.S. DOE

ATLAS HL-LHC Upgrades (4)

- Enabling Triggering at the HL-LHC
  - new readout electronics in LAr & Tile Calorimeters
    - all data off-detector at 40 MHz bunch-cross frequency
    - more sophisticated algo's at L1
  - new readout electronics in all Muon sub-systems
    - all data off-detector at 1 MHz
  - addition of MDT info to L0
    - sharper turnon curves
  - new trigger architecture
    - split L0/L1
    - silicon tracking at L1 (L1Track) & EF (FTK++)
    - combine fine-grained Calo info with Track and Muon (L1Global)
  - muon geometrical acceptance
    - new RPSs & sMDTs
    - efficiency: 65% → 95%





U.S. NSF

ATLAS HL-LHC – US Scope

- Proposed US Scope matches unique US expertise
  - builds on experience in original ATLAS construction & Phase-I
  - ongoing R&D aimed at these scope items
- Two categories of scope
  - "Baseline" Scope: fits within DOE and NSF funding guidance
    - prioritized to identify "Scope Contingency": scope to be dropped if total budget over-runs are anticipated
  - "Opportunity" Scope: additional scope matching US expertise
    - could be added if funds become available (contingency reduction,...)
    - indicated in gray in the following slides
- WBS Structure (6.x.y.z) designed to streamline reporting
  - Level-2 (x): System
  - Level-3 (y): Institute
  - Level-4 (z): Deliverable (each deliverable may contain separate Items)
- Clear split between DOE and NSF scope at Deliverable Level (along thematic lines)
  - DOE: *Tracking and Data-Handling*
  - NSF: *Enabling Triggering at the HL-LHC*

US Scope - DOE

WBS		Deliverable	Funding	Institutes	US Expertise
6.1	**Pixels**			**Philippe Grenier (SLAC)**	
	6.1.y.1	Pixels Integration	DOE	LBNL	Pixels in original detector & IBL
	6.1.y.2	Pixel Mechanics	DOE	LBNL, Washington	
	6.1.y.3	Pixels Services	DOE	OSU, SLAC	
	6.1.y.4	Local Supports	DOE	ANL, LBNL, SLAC, UCSC, UNM	
	6.1.y.5	Pixels Modules	DOE	ANL, LBNL, OKU, UCSC, UNM, Wash, Wisc	
	6.1.y.6	Off-Detector Electronics	DOE	OKS	
	6.1.y.7	Support	DOE	ANL, SB, SLAC, UNM, Washington	
6.2	**Strips**			**Carl Haber (LBNL)**	
	6.2.y.1	Stave Cores	DOE	BNL, IowaSt, LBNL, Yale	Strips in original detector
	6.2.y.2	Readout/Control Chips	DOE	BNL, LBNL, Penn, UCSC, Yale	
	6.2.y.3	Modules & Integration	DOE	BNL, Duke, LBNL, Penn, UCSC, TBD	
6.3	**Global Mechanics**			**Eric Anderssen (LBNL)**	
	6.3.y.1	Integration System Test	DOE	Indiana, LBNL, SLAC, UCSC	Mechanics in original detector
	6.3.y.2	Outer Cylinder & Bulkhead	DOE	LBNL	Low-mass support structures
	6.3.y.3	Thermal Barrier	DOE	SLAC	
	6.3.y.4	Pixel Support Tube	DOE	LBNL	
	6.3.y.5	DAQ Interface	DOE	SLAC, Washington	
6.4	**Liquid Argon**			**John Parsons (Columbia)**	
	6.4.y.4	System Integration	DOE	BNL	Similar syst. int. tests for original detector
	6.4.y.5	PA/Shaper	DOE	BNL, Penn	FE ASICs for original detector & Phase-I
	6.4.y.6	sFCAL	DOE	Arizona	FCAL in original detector
	6.4.y.7	HGTD	DOE	Iowa, Penn, SLAC, UCSC	Leverage ongoing US R&D
6.7	**DAQ/Data Handling**			**Jinlong Zhang (ANL)**	
	6.7.y.1	L1Global Aggregator	DOE	BNL	Phase-I gFEX
	6.7.y.2	L1Track/FTK++ Data	DOE	ANL, SLAC	Phase-0/1 FTK
	6.7.y.3	DAQ/FELIX	DOE	ANL, BNL	Phase-I FELIX
	6.7.y.4	RoID	DOE	ANL	Phase-I gFEX

US Scope - NSF

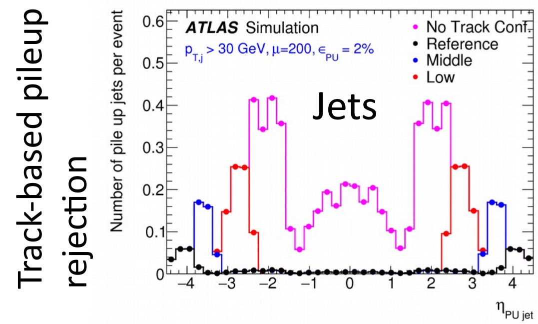
WBS		Deliverable	Funding	Institutes	US Expertise
6.4	**Liquid Argon**			**John Parsons (Columbia)**	
	6.4.y.1	Front End Electronics	NSF	Columbia, UTAustin	FE ASICs and FEB in orig detector & Phase-I
	6.4.y.2	Optics	NSF	SMU	Optics in original detector & Phase-I
	6.4.y.3	Back End Electronics	NSF	Arizona, SB	Phase-I LAr Digital Processing System
6.5	**Tile Calorimeter**			**Mark Oreglia (Chicago)**	
	6.5.y.1	Main Board	NSF	Chicago	MB in original detector
	6.5.y.2	Pre-Processor Interface	NSF	UTArlington	involvement in original sROD
	6.5.y.3	ELMB++ Motherboard	NSF	MSU	Tile DCS in original detector
	6.5.y.4	Low Voltage Power Supply	NSF	NIU, UTArlingron	Tile LVPS in Phase-0
6.6	**Muon**			**Tom Schwarz (Michigan)**	
	6.6.y.1	PCB for Mezzanine	NSF	Arizona	similar projects in original detector
	6.6.y.2	TDC	NSF	Michigan	extensive ASIC design experience
	6.6.y.3	CSM	NSF	Michigan	original detector
	6.6.y.4	Hit Extraction Board	NSF	Illinois	board design experience on CDF
	6.6.y.5	sMDT Chambers	NSF	Michigan, MSU	MDT production in original detector
6.8	**Trigger**			**Elliot Lipeles (Penn)**	
	6.8.y.1	L0Calo	NSF	MSU	built Phase-I system
	6.8.y.2	L0Muon	NSF	Irvine	extensive design experience at Irvine
	6.8.y.3	L1Global	NSF	Chicago, Indiana, LSU, MSU, Oregon, Pitt	Phase-I gFEX
	6.8.y.4	L1Track/FTK++ Processing	NSF	Indiana, Penn, Chicago, Illinois, NIU, Stanford	Phase-0/I FTK

Scope → Physics

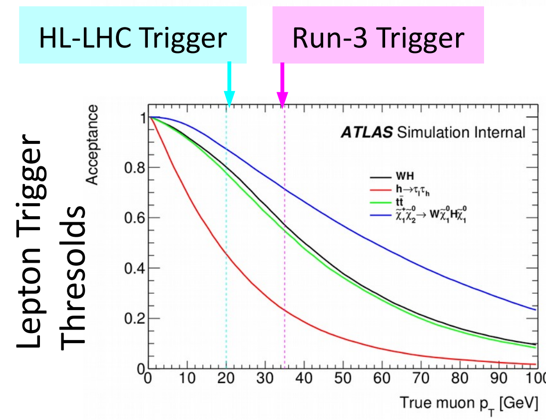
- Multi-Dimensional, Correlated Mapping
  - single measurement (science goals) depends on multiple objects (e,μ,jet,...)
  - object performance (sience req) depends on multiple detector parameters (tech requirements)
  - general summary + specific examples below
    - more details in backup & Scoping Document

Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
Object Performance / Physics Process	Efficiency/ Thresholds						
	$\mu^\pm$	$e^\pm$	b-tagging	$\mu^\pm$ Identification/ Resolution	Pile-up rejection	Jets	E_T^{miss}
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^\pm\chi_2^o \rightarrow \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \rightarrow b\bar{b}b\bar{b}$			✓			✓	

- Science Requirements: Tracking-related (DOE)
  - goal: maintain Run-1 performance in HL-LHC
  - object identification (e,μ,τ,jet,b-jet) <== track association
  - pileup rejection <== associate jets to pp collision vertices



- Science Requirements: Trigger-related (NSF)
  - goal: maintain Run-1 efficiency in HL-LHC
  - low thresholds (more sophisticated algorithms)
  - higher allowed rates



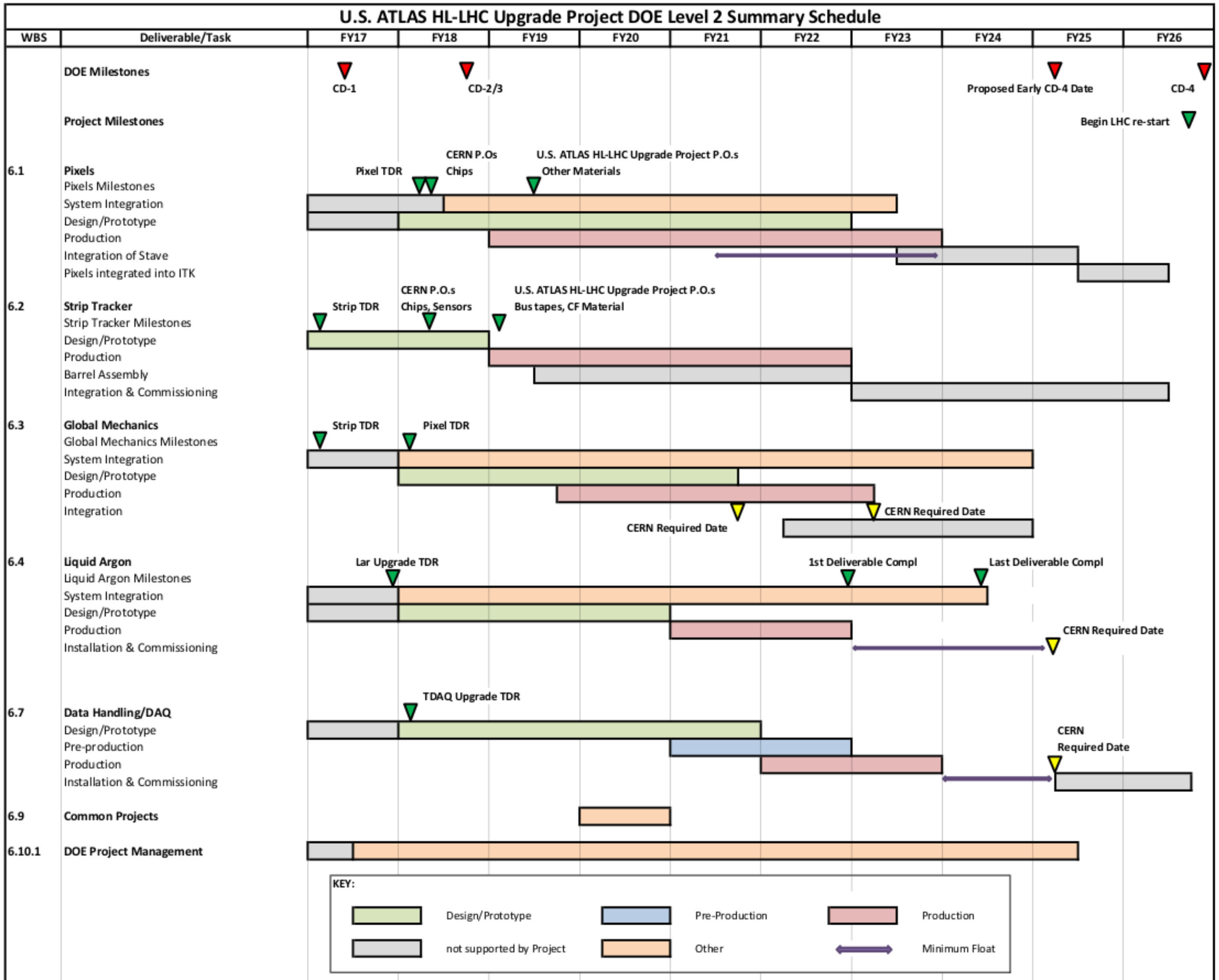
Upcoming Technical Decisions

System	TDR	Technical Decision (Date)
Pixels	Q4 2017	• η coverage: 4.0 vs 3.2 (Sep. 2016) • layout/mechanics: flat vs inclined modules (Sep. 2016)
Strips	Q4 2016	• layout: move to 4-strip/5-pixel layers (Summer 2015)
Global Mech		• Thermal shield: integrated with Outer Cylinder or not (strip TDR)
Liquid Argon	Q3 2017	• PA/Shaper technology: BNL vs French (TDR) • sFCAL yes or no (Jun. 2016) • HGTD yes or no (May 2017)
TileCal	Q4 2017	• FE chip: 3-in-1, QIE, FATALIC (Sep. 2017)
Muon	Q2 2017	• TDC technology: ASIC, FPGA, VMM-like (TDR) • accessibility of inner chambers (TDR)
Trigger & DAQ	Q4 2017	• architecture: L0/L1 vs L1-only (Summer 2016)

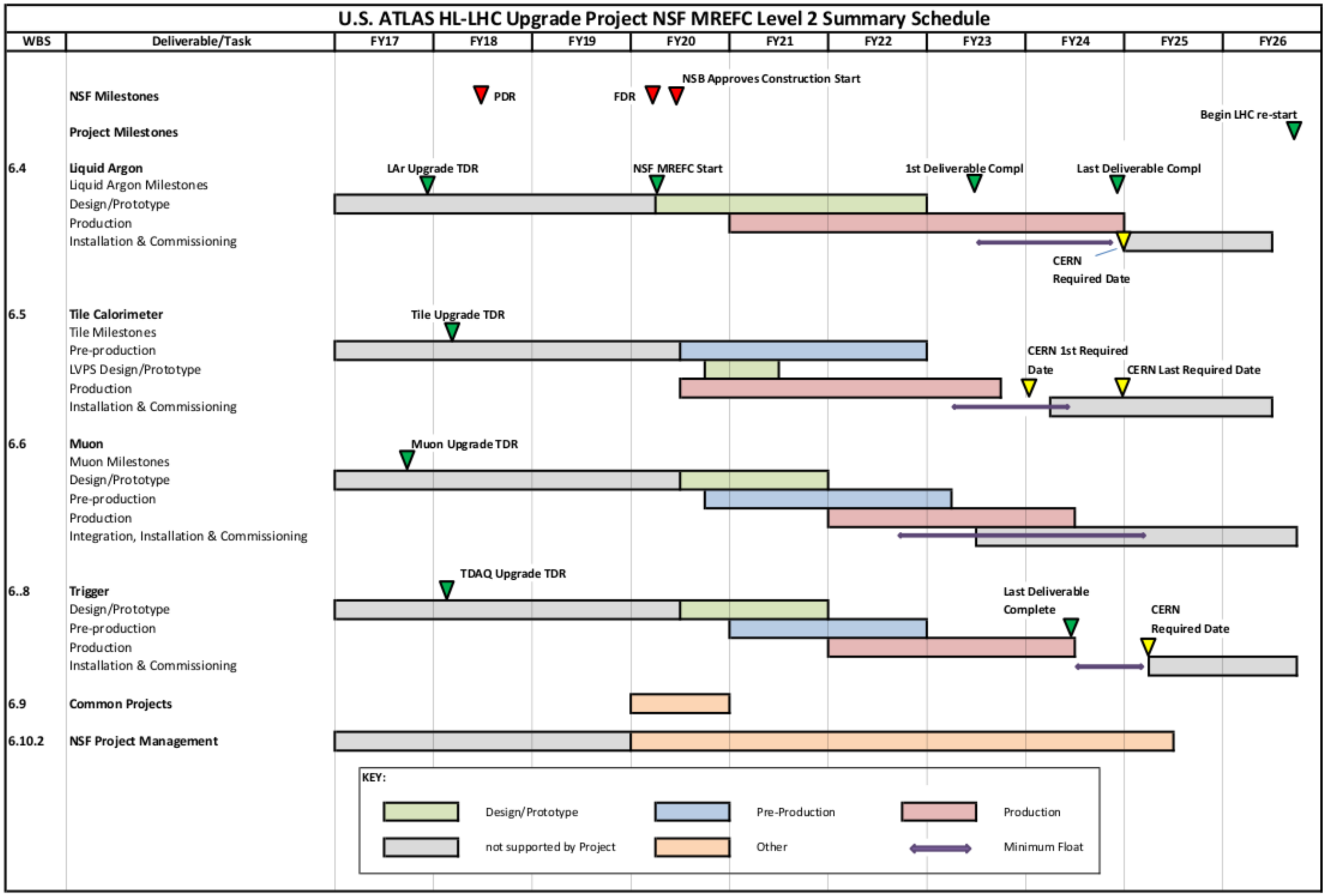
Research & Development

- HL-LHC R&D ongoing for several years already
  - ==> quite well-defined ATLAS HL-LHC detector
- ATLAS R&D program over next few years aimed at
  - resolving technical decisions & preparing for TDRs
- Robust R&D program in US (details in breakout sessions)
  - Pixels: FE chip, high-speed readout, support structures, serial powering, module assembly, stave loading
  - Strips: 14-module stave core, complete 1 MHz chipset, module assembly sites
  - Global Mechanics: define envelopes (support, services, endplate)
  - LAr: custom ASICs (65nm PA/Shaper, ADC, Serializer), sFCAL studies
  - TileCal: drawer demonstrator in testbeams and ATLAS
  - Muon: demonstrator electronics (TDC, CCM, HEB), sMDT tube/chamber sites
  - Trigger: ongoing Phase-I program, L1Track demonstrator
  - DAQ/Data Handling: ongoing Phase-I program, FPGAs & opto-links for high-speed data handling

US Schedule (DOE)



US Schedule (NSF)



Risk & Contingency

- Budget Contingency: funds set aside to cover possible cost over-runs
  - (1) from deliverable risk analysis & (2) at global level (cross-system)
    - currently estimated top-down for each L2 system – see Srini's talk
  - moving to bottom-up estimate based in Item-level risks
- Schedule Contingency: slack in schedule (float in Timeline charts)
  - float = time between end of production and “required at CERN”
    - note: required at CERN dates are evolving as ATLAS plans evolve
  - see L2 talks for details
- Scope Contingency: essentially a prioritization
  - what elements of the project could be dropped if we anticipate over-running our total budget (base + budget contingency)
    - timing of when scope contingency can be realized is crucial
  - see backup for a summary & L2 talks for details

Scope Opportunity

- As project becomes better defined
  - budget contingency decreases
  - adjustments to US scope may also occur
- Each L2 system maintains a list of additional scope that could be added should funds become available
  - decisions need to be made at time of system TDRs (responsibilities defined)
  - maintain some level of US R&D in these Opportunity areas in case they are realized
  - see backup for a summary & L2 talks for details

Conclusions

- Strong motivation for ATLAS HL-LHC upgrade
  - HL-LHC ==> physics opportunities & technical challenges for ATLAS
- Clear US scope proposal that meets funding guidance
  - result of extensive discussion with ATLAS – finalize on TDR timescales
  - builds on unique US expertise and experience
  - DOE scope: Tracking and Data Handling
  - NSF scope: Enabling Triggering at the HL-LHC
- Extensive R&D program in the US
  - aimed at preparing for construction of US scope
  - provide input to short-term technical decisions and TDRs

BACKUP

Summary of Scoping Scenarios

- The HL-LHC ATLAS Reference Scenario allows us to meet our Science Requirements and HL-LHC Physics Goals
  - Have studied sensitivity to meeting these requirements by considering two less ambitious scenarios (details in Scoping Document)
- Main differences
  - reduce tracking & trigger coverage from $|\eta| < 4.0 \rightarrow 3.2 \rightarrow 2.7$
  - reduce maximum allowed trigger rates and increase L1Track thresholds
  - reduce muon system trigger coverage

ATLAS Scoping Scenarios: ITK & Calo

Detector System	Scoping Scenarios: Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Inner Tracker			
Pixel Detector	$\lvert\eta\rvert \leq 4.0$	$\lvert\eta\rvert \leq 3.2$	$\lvert\eta\rvert \leq 2.7$
Barrel Strip Detector	✓	✓ [No stub layer]	✓ [No stereo in layers #2,#4] [Remove layer #3] [No stub layer]
Endcap Strip Detector	✓	✓ [Remove 1 disk/side]	✓ [Remove 1 disk/side]
Calorimeters			
LAr Calorimeter Electronics	✓	✓	✓
Tile Calorimeter Electronics	✓	✓	✓
Forward Calorimeter	✓	✗	✗
High Granularity Precision Timing Detector	✓	✗	✗

ATLAS Scoping Scenarios: Muon

Muon Spectrometer	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Barrel Detectors and Electronics			
RPC Trigger Electronics	✓	✓	✓
MDT Front-End and readout electronics (BI+BM+BO)	✓	✓ [BM+BO only]	✓ [BM+BO only]
RPC Inner layer in the whole layer	✓	✓ [in half layer only]	✗
Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only]
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

ATLAS Scoping Scenarios: TDAQ

Trigger and Data Acquisition	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Level-0 Trigger System			
Central Trigger	✓	✓	✓
Calorimeter Trigger (e/γ)	$\|\eta\| < 4.0$	$\|\eta\| < 3.2$	$\|\eta\| < 2.5$
Muon Barrel Trigger	MDT everywhere RPC-BI Tile-μ	MDT (BM & BO only) Partial η coverage RPC-BI Tile-μ	MDT (BM & BO only) No RPC-BI Tile-μ
Muon End-cap Trigger	MDT everywhere	MDT (EE&EM only)	MDT (EE&EM only)
Level-1 Trigger System			
Output Rate [kHz]	400	200	200
Central Trigger	✓	✓	✓
Global Trigger	✓	✓	✓
Level-1 Track Trigger (*RoI based tracking*)	$p_T > 4$ GeV $\|\eta\| \leq 4.0$	$p_T > 4$ GeV $\|\eta\| \leq 3.2$	$p_T > 8$ GeV $\|\eta\| \leq 2.7$
High-Level Trigger			
FTK++ (*Full tracking*)	$p_T > 1$ GeV 100 kHz	$p_T > 1$ GeV 50 kHz	$p_T > 2$ GeV 50 kHz
Event Filter	10 kHz output	5 kHz	5 kHz
DAQ			
Detector Readout	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]
DataFlow	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]

ATLAS CORE Costs: Scoping Doc

WBS	Detector system	Reference Detector Total Cost [MCHF]	Middle Scenario Differential Cost [MHCF]	Low Scenario Differential Cost [MCHF]
	ATLAS	**271.04**	**-42.55**	**-71.16**
1.	TDAQ	43.31	-11.41	-18.19
1.1	L0 Central Trigger	1.21	-	-
1.2	L0 Calorimeter Trigger	0.70	-	-0.24
1.3	L0 End-cap Muon	2.56	-0.11	-0.11
1.4	L0 Barrel Muon	1.32	-0.14	-0.17
1.5	L1 Central Trigger	1.93	-	-
1.6	L1 Global Trigger	3.39	-	-
1.7	L1 Track	4.19	-0.67	-2.49
1.8	FTK++	13.03	-4.88	-9.56
1.9	DAQ/Event Filter	14.98	-5.62	-5.62
2.	ITk	120.36	-7.2	-23.6
2.1	Pixel	32.19	-0.9	-4.8
2.2	Strip	72.10	-6.3	-18.8
2.3	Common Items	16.08	-	-
3.	LAr	45.98	-13.60	-13.60
3.1	Read-out electronics	31.39	-	-
3.2	sFCal	10.03	-10.03	-10.03
3.3	HGTD	4.56	-4.56	-4.56
3.4	LAr MiniFCal		*+0.91*	
3.5	Si-based MiniFCal		*+3.57*	
4.	Tile	8.58	-	-
5.	Muon	34.08	-8.78	-12.79
5.1	MDT	7.69	-2.07	-3.16
5.2	RPC	7.99	-2.32	-4.79
5.3	TGC	4.44	-	-
5.4	High-Eta Tagger	3.50	-3.50	-3.50
5.5	Power System	10.47	-0.89	-1.34
6.	Forward	1.30	-	-
7.	Integration & Installation	17.42	-1.56	-2.98

Linking Scope to Physics

- ATLAS has a very broad physics program
  - Higgs, New Physics, Standard Model, Heavy Flavor, QCD, Heavy Ion...
  - 501 physics publications as of end-2015
- All elements of ATLAS detector contribute to Physics Sensitivity
  - 100's of individual detector/trigger parameters have significant impact on results
    - cannot study the impact of each of these independently
  - in Scoping Document ATLAS chose 3 Detector Configurations to study sensitivity to varying assumptions about the HL-LHC upgrade detector
- Multi-Dimensional nature of flow from Science Goals ==> Detector Requirements
  - Physics Sensitivity <== performance in identifying Objects (e, μ, jets,...)
    - effic, resolution, etc. of multiple objects contribute significantly to individual result
  - Object Performance <== individual Detector/Trigger elements
    - multiple detector/trigger elements contribute significantly to each object
  - see backup slides for more details...

NSF Scope to Physics

Trig Objects ==> Physics

	Trigger Object					
Channel	e	μ	τ	Jet	Fat Jet	E_T^{miss}
$H \rightarrow 4\mu$		√				
VBF $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$	√	√	√	√		
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	√	√		√		√
VBS ssWW	√	√		√		
SUSY $\chi_1^{\pm}\chi_2^0 \rightarrow \ell bb + X$	√	√		√		√
BSM $HH \rightarrow 4b$					√	

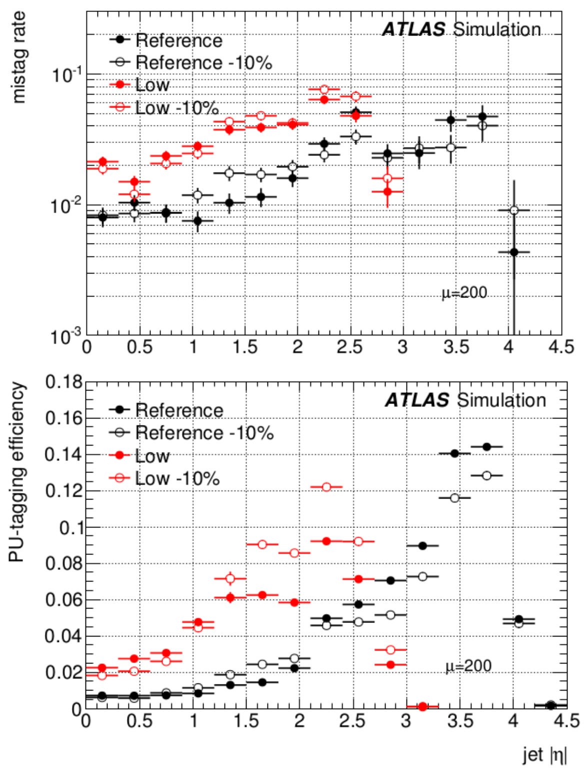
US Scope ==> Trig Obj's

Upgrade	e	μ	τ	Jet	Fat Jet	E_T^{miss}
Trigger Upgrades						
L0 Calorimeter	√		√	√	√	√
L0 Muon		√				√
L1 Track	√	√	√	√		√
L1 Global	√	√		√	√	√
Calorimeter Upgrades						
LAr Electronics	√		√	√	√	√
Tile Electronics		√		√	√	√
Muon Upgrade						
sMDT Chambers		√				√
Muon Electronics		√				√

DOE Scope to Physics

- Tracking
  - efficiency/resolution
    - object ID (especially: e,μ,τ,b-jet)
  - η-coverage:
    - jet reconstruction (VBF, VBS)
    - pileup (forward jet vertex association)
    - E_t^{miss} (pileup jet rejection)

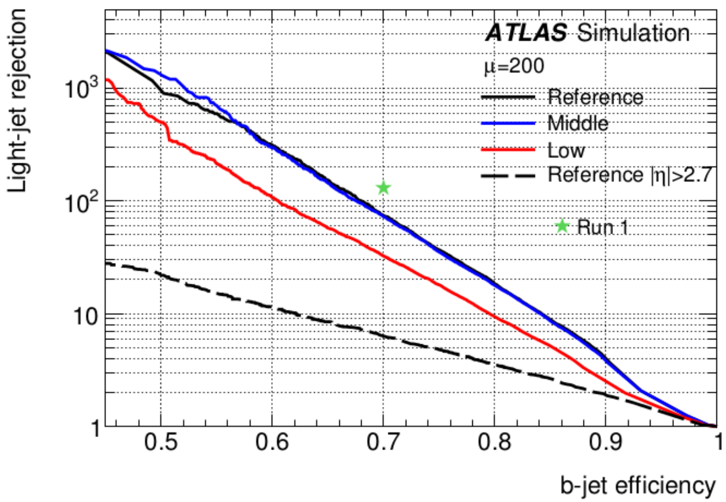
b-tagging in ttbar events



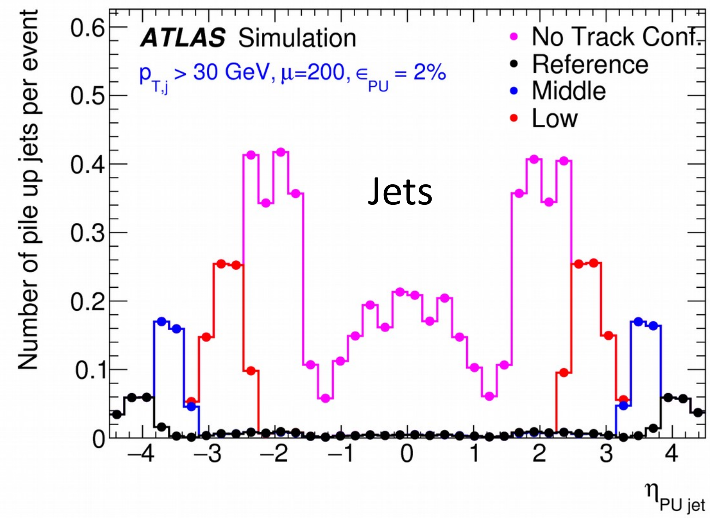
- DAQ/Data Handling
  - increase trigger efficiency by allowing higher rates

Impact of Tracking Upgrades (cont)

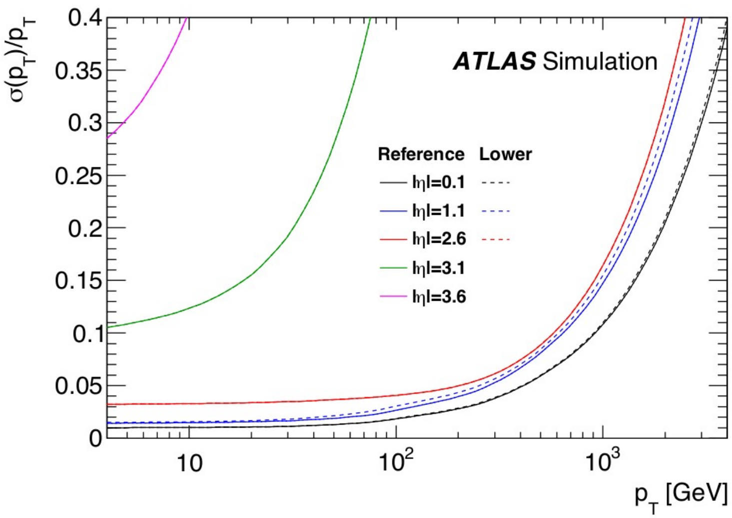
b-Tagging

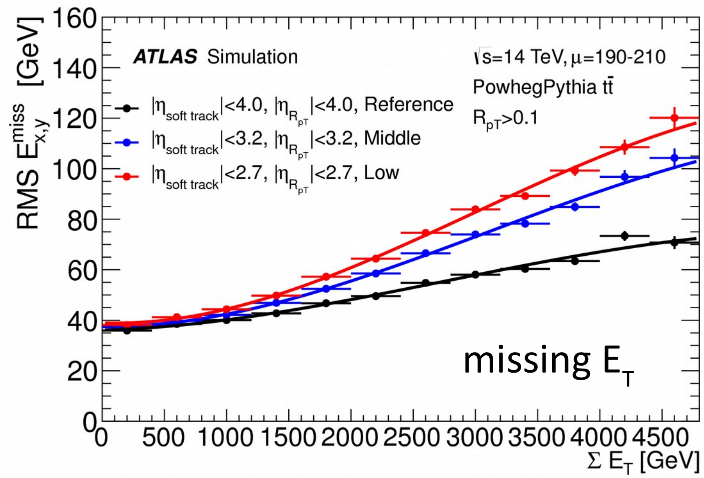


Track-based pileup rejection



μ Momentum Resolution: ITK+Muon





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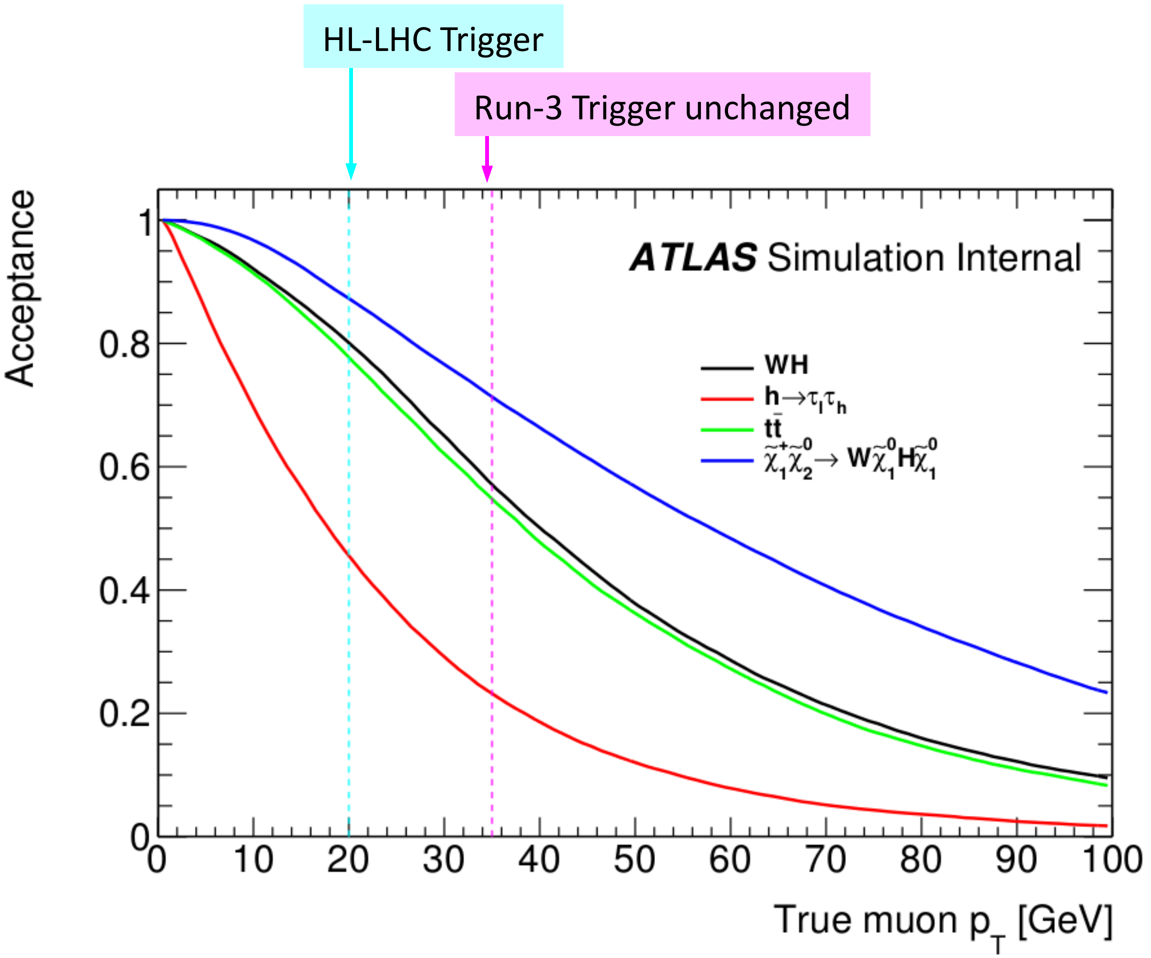
Impact of Trigger/DAQ Upgrades

Simplified HL-LHC Trigger Menu

item	Reference p_{T} Threshold [GeV]	$\|\eta\|$	Eff.
iso. Single e	22	< 2.5	95%
forward e	35	$2.5 - 4.0$	90%
single γ	120	< 2.4	100%
single μ	20	< 2.4	95%
di-γ	25	< 2.4	100%
di-e	15	< 2.5	90%
di-μ	11	< 2.4	90%
$e - \mu$	15	< 2.4	90%
single τ	150	< 2.5	80%
di-τ	40,30	< 2.5	65%
single jet	180	< 3.2	90%
fat jet	375	< 3.2	90%
four-jet	75	< 3.2	90%
HT	500	< 3.2	90%
E_T^{miss}	200	< 4.9	90%
jet + E_T^{miss}	140,125	< 4.9	90%
forward jet**	180	3.2 - 4.9	90%



Trigger: Scope Sensitivity

item	Reference			Middle			Low		
	p_T Threshold [GeV]	$\|\eta\|$	Eff.	p_T Thr. Threshold [GeV]	$\|\eta\|$	Eff.	p_T Thr. Threshold [GeV]	$\|\eta\|$	Eff.
iso. Single e	22	< 2.5	95%	28	< 2.5	95%	28	< 2.5	91%
forward e	35	$2.5 - 4.0$	90%	40	$2.5 - 3.2$	90%	-	-	-
single γ	120	< 2.4	100%	120	< 2.4	100%	120	< 2.4	100%
single μ	20	< 2.4	95%	25	< 2.4	80%	25	< 2.4	65%
di-γ	25	< 2.4	100%	25	< 2.4	100%	25	< 2.4	100%
di-e	15	< 2.5	90%	15	< 2.5	90%	15	< 2.5	82%
di-μ	11	< 2.4	90%	15	< 2.4	80%	15	< 2.4	65%
$e - \mu$	15	< 2.4	90%	15	< 2.4	84%	15	< 2.4	70%
single τ	150	< 2.5	80%	150	< 2.5	80%	150	< 2.5	80%
di-τ	40,30	< 2.5	65%	50,40	< 2.5	65%	50,40	< 2.5	55%
single jet	180	< 3.2	90%	225	< 3.2	90%	275	< 3.2	90%
fat jet	375	< 3.2	90%	400	< 3.2	90%	450	< 3.2	90%
four-jet	75	< 3.2	90%	85	< 3.2	90%	90	< 3.2	90%
HT	500	< 3.2	90%	600	< 3.2	90%	750	< 3.2	90%
E_T^{miss}	200	< 4.9	90%	225	< 4.9	90%	250	< 4.9	90%
jet + E_T^{miss}	140,125	< 4.9	90%	150,175	< 4.9	90%	160,200	< 4.9	90%
forward jet**	180	3.2 - 4.9	90%	225	3.2 - 4.9	90%	275	3.2 - 4.9	90%

Scope Contingency Summary

System	Scope Contingency	Savings	Impact/Assumption
6.1 Pixels	reduce: LV power, supports, stave flex, bump bonding, modules	\$3.2M	materials picked up by others
6.2 Strips	deliver less cores/modules/staves	var	UK can do more
6.3 Global Mech	thermal barrier	\$0.3M	may not be required
6.4 Liquid Argon	less firmware for BE produce less FEB2/Otx/BE Mbs drop PA/shaper	\$1M \$1M \$1M	find other groups may lose leadership may ==> non-opt readout
6.5 TileCal	drop LV box assembly	\$0.4M	find other group
6.6 Muon	drop HEB	\$2.2M	may not be needed
6.7 DAQ/Data	produce less L1Track/FTK++ RTMs	\$0.7M	find other partners
6.8 Trigger	drop 1 L1Global Algorithm produce less L1Track/FTK++ MBs	\$0.4M \$1.1M	find other group find others or reduced eff.

Scope Opportunity Summary

System	Scope Contingency	Cost	Benefit/Motivation
6.1 Pixels	• buy 20% of sensors (cf 0%)	\$1.7M	modules use US sensors
6.2 Strips	• none	---	main areas assigned
6.3 Global Mech	• common electr. (DAQ)	\$1.5M	US experience here
6.4 Liquid Argon	• sFCAL • HGTD	\$5.4M \$5.3M	US-led effort significant US leadership
6.5 TileCal	• produce all LVPS (cf 50%)	\$1.1M	reduce external dependency
6.6 Muon			
6.7 DAQ/Data	• prod all L1Global aggr's (cf 50%) • 30% FELIX card prod (cf 15%)	\$0.7M \$0.5M	reduce external dependency all needed for ITK integration
6.8 Trigger	• add 1 L1Global Algo	\$0.4M	US expertise here